Future of Biometric Technology in Healthcare Simulation

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Summary Statement: Biometric technology shows substantial promise to enhance patient safety and transform provider training. In patient care, biometric technology enables outpatient providers to optimize chronic disease by alerting providers to changes in patient conditions with real-time data. In provider training, biometric technology can inform training environments and curriculum. Certainly, there are hurdles to technology implementation including hardware fragility, cost, and software integration. Despite challenges, biometric technology has been effectively implemented in simulations and real patient settings.

Looking forward, future developments focused on data security and privacy, standardizing data collection, and improving system compatibility will facilitate the wider adoption of biometric technology and improve health care quality, especially in resource-limited settings. Collaborative efforts among informatics experts, patient safety advocates, and health care providers are essential to overcome challenges and fully leverage biometric technology's potential in enhancing patient outcomes. The purpose of this commentary is to review current applications, identify key challenges, and offer recommendations to the simulation community for testing biometric technology, use in training programs, and facilitating systems integration to improve outcomes.

Key Words: Biometric, wearable, technology, simulation, telehealth

(*Sim Healthcare* 2026;21:252–256)

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Disclosures: T.G. discloses employment with HealthySimulation.com. B.A.R. discloses employment as an Associate Editor for *Clinical Simulation in Nursing*. The other authors declare no conflict of interest.

ISSN: 1559-2332
DOI: 10.1097/SIH.0000000000000875

Biometric technology includes a variety of equipment used to measure physical characteristics and behavior tracking.[1] Historically utilized by government organizations for access control, identification, and tracking movements, biometric technology has now expanded its reach.[2] Using biometrics to identify individuals through their interactions with technology, industries link data from wearable technology to workforce outcomes and productivity.[1] An example of innovation and response to evolving health care needs, biometric technology can directly improve patient outcomes when used for monitoring physical characteristics and behavior. Biometric technology can alert providers to changing patient status so they are able to intervene to prevent patient safety events; as a supplement to in-person health care, biometric technology allows for ongoing monitoring of objective data trends for patients with acute and chronic conditions.[3,4] Preventing patient safety events has been a long-term focus of improving health care quality, and it aligns with legislation introduced in March 2024 through House Resolution 7951 to establish a National Patient Safety Board.[5] On a larger scale, industry partners use biometric data to forecast global health, epidemiology, and prevention.[6] Research also includes psychological interventions and samples including individuals with rare diseases and underrepresented populations.[6]

Testing biometric technology in health care simulation is the next logical step to advance patient outcomes as simulation approximates a real clinical environment with more control than is possible in a traditional clinical setting. Simulation is a ripe ecosystem to test biometric technology, particularly owing to standardization of simulation environments that optimize wearable data capture.[1] Standardization allows for the study of how biometric data can be integrated into clinical workflows to enhance decision-making and patient care, especially because data from providers can be linked to human factors conditions created in the simulation laboratory to mimic actual clinical environments. By simulating clinical environments, researchers, educators, and technologists can observe the direct impacts of biometric technology on clinical outcomes, thereby refining its applications and ensuring more robust implementations in real-world settings.

The purpose of this commentary is to review current applications, identify key challenges, and offer recommendations to the simulation community for testing biometric technology, use in training programs, and facilitating systems integration to improve patient outcomes.

TECHNOLOGY DESCRIPTION

Biometrics are frequently noninvasive, wearable technology used in naturalistic environments. Technology may be worn on a finger, wrist, arm, hip, or chest to capture physiologic data including vital signs, blood volume changes, energy expenditure, sleep, blood glucose, and movement.[6] Commercially available smartwatches and fitness trackers have evolved into wearable trackers (eg, biometric shirt or ring) and technology-enhanced surveillance like smart inhalers. Many trackers are affordable, accurate, valid, and have certifications; their objectivity is superior to self-reported outcomes, reliable, and easy to generate.[6] Patients are generally willing to use biometric technology at home as a monitor for treatment efficacy.[7] Providers reported high satisfaction wearing accelerometers and 2-lead electrocardiograms in a 3-day surgical boot camp where they logged technical and nontechnical training, sleep, meals, exercise, alcohol, caffeine, and events perceived as sources of stress.[8]

More sophisticated biometric technology may require sensors and wires connected to recording units that limit mobility. Researchers have used eye tracking glasses to help understand providers' situational awareness,[9,10] galvanic skin response combined with eye tracking to describe cognitive load,[11] and smart glasses with augmented reality interventions as feedback during cardiopulmonary resuscitation.[12]

Biometric technology has been integrated into uncontrolled environments in the form of ambient intelligence. Using passive, radio wave-based home monitoring, researchers detect gait speed changes, home activity, and time in bed with patients who have Parkinson disease and correlate biometric data with subjective scales to monitor treatment efficacy.[7] Biometric home monitoring introduces new concerns for data security but also opportunities for ambient intelligence (eg, smart environment to lower lights and promote mindfulness) and individualized alerts prompting interventions to improve patient outcomes.

The literature surrounding wearable biometric technology highlights that hardware and software are user friendly.[6] Users report positive aspects include sampling rate, battery life, large memory space, raw data availability, and compatibility with smart phones and application programming interfaces (API). Although biometric technology can be fragile, users value the benefits and motivational impact associated with wearable technology for behavior change.[6] Many devices use Bluetooth to communicate with mobile applications, but more robust biometric technology used for research typically requires expensive hardware configuration and compatibility. For example, hardware components such as dedicated video cards and solid-state drives (SSD) can be cost-prohibitive. Further, applications that require a separate device per software license increase initial and ongoing hardware costs.

A downside of software used with biometric technology is that it usually requires a subscription or membership fee; licensing can be cost-prohibitive if software allows only 1 user per license.[6] Software requirements vary by vendor and can involve frequent updates. Vendors may change source code or implement technical updates without warning or detailing changes that impact usability and could bias data or contribute to inconsistency.[13] For example, software updates limit compatibility with peer applications and devices across operating systems; as a result, users have limited ability to synchronize and export data. Software may allow researchers to complete the first-pass for analysis,[14] but more detailed annotation and analysis may require secondary software and additional cost. For example, users can connect the recording device from a wearable biometric shirt to a computer using a universal serial bus (USB) cable to upload data to cloud-based software; software can show trends in vital signs data on a dashboard, but researchers likely need secondary software to calculate heart rate variability.

Users encounter many challenges related to gaps in system integration especially when utilizing several biometrics concurrently. Vendors' proprietary software frequently prevents systems from communicating across platforms even if they use the same programming language. Though proprietary language increases quality control from the vendor's perspective, it limits acceptance in simulation and health care. Users want more access to raw data and to vendors' algorithms.[6] A negative consequence of barriers to system integration is that data from biometric technology requires either temporary or permanent storage on secure digital (SD) cards, which are easily misplaced or mislabeled.

Use Cases for Biometric Technology in Simulation and With Patients

Simulation learners, simulated patients, operations specialists, and facilitators can wear biometric technology to identify how simulation design and human factors impact providers, [14–16] including comparing novice to expert providers' responses to similar simulation cues.[9] Biometric technology used in simulation helps researchers to explore the effects of human factors on medical error and clinical decision-making across professions and levels of expertise. The controlled environment of a simulation allows for detailed studies into provider health and the impact of stress, anxiety, emotional bias, cognitive load, fatigue, and burnout.[8] Simulation also enables comparative effectiveness research across different modalities and practice settings to examine how the environment influences performance.[17] In simulation research, individuals often serve as their own controls (ie, comparing baseline data to data collected during simulation) or simulation learners are matched to healthy peers.

Researchers have successfully implemented biometric technology with actual patients. Huhn and col-

TABLE 1. Key Roles and Benefits Health Care Simulation Can Play in Enhancing the Capabilities and Integration of Biometric Technologies in Clinical Settings

Role	Benefits	Practical Example
Testing and Validation	Provides a controlled environment for testing, allows for real-time adjustments, and ensures consistent conditions for technology validation.	**Testing** a new biometric scanner in a simulated emergency department to assess its speed, accuracy, and scalability with large patient volumes. **Validating** voice recognition with black box technology to analyze mood to alert providers of increased likelihood of exacerbating a chronic mental illness.
Integration into Clinical Workflows	Helps integrate biometric devices into health care workflows, identifies practical challenges, and improves device design through clinician feedback.	**Integrating** a biometric patient monitoring system in a simulated intensive care unit to alert clinicians to a changing patient's status and optimize staff response times.
Training and Education	Enhances clinician familiarity and adoption, facilitates hands-on learning, and supports skill development in using biometric data.	**Training** sessions using virtual reality to increase adoption of biometric data to improve patient identification across allied health services, including radiology, nutrition, physical therapy, and speech pathology.
Human Factors Testing	Tests device ergonomics and usability, analyzes impact on clinical decision-making, and assesses cognitive load on users.	**Evaluating** the usability of wearable biometric devices in a realistic simulation environment representing a busy clinic setting.
Safety and Efficacy	Evaluates potential impacts on patient safety, allows for risk mitigation, and measures effectiveness through outcome comparison.	**Simulating** in situ team resuscitation to test the efficacy of a biometric-enabled drug delivery system.
Regulatory Compliance and Standardization	Ensures biometric technologies comply with regulatory standards and aids in developing standardized protocols for use across health care settings.	Using tabletop simulation to test and refine biometric data handling procedures to ensure compliance **with privacy regulations**.
Innovation and Development	Drives rapid innovation cycles, facilitates immediate improvements based on clinician feedback, and encourages cross-disciplinary collaboration.	**Prototyping** a new biometric sensor with iterative feedback loops in simulated residential setting to allow prosthetic limb users to perform more natural movements.

leagues identified a diverse array of applications across health care specialties and geographic areas.[6] For example, clinicians use built-in surveillance within durable medical equipment to monitor use versus abandonment.[18] Biometric home monitoring allows for asynchronous or synchronous telehealth[19] and management of chronic conditions.[20,21] For example, encrypted data captured at home can be transferred via wireless networks (Wi-Fi) over a secure file server.[7]

Challenges and Future Directions of Biometric Technology Integration

North America dominated the global biometric market in 2023.[22] The global biometric market is expected to grow from 10.6 billion USD in 2016 to an estimated 41.39 billion USD by 2025.[15] Research applications represented by biometric technology are opening up new datasets and opportunities; continuous biometric monitoring contributes to big data, generating new evidence,[23] providing insight into patient experiences with chronic conditions, and enabling providers to personalize health care and evaluate therapeutic responses.[7] Health scientists predict big data extracted from wearable biometric technology may transform the understanding of population health dynamics and the ability to forecast health trends.[6]

Concerns Related to Safety and Privacy

In the pursuit to broaden adoption of wearable technology, we recognize that safety and privacy concerns are significant barriers.[6,13] Although laws governing biometrics are evolving, there is considerable variation across jurisdictions.[1] Data security and privacy are stringently regulated by European Union General Data Protection Regulation,[24] yet there remains a pressing need for more uniformity and standardized recommendations for the networks that collect biometric data. Unfortunately, the highest instances of data theft are in information technology and health care sectors.[22] Though biometrics are a solution to decrease data theft through secure identity, if biometric data such as facial recognition, fingerprint, and periocular image is compromised, it is irreplaceable, highlighting the need for effective protection measures.[1,25]

Moreover, there is a need for clear regulatory guidance to safeguard biometric data and define ownership and responsibility in the event of a security breach. Although protecting these data can be challenging, there are successful precedents, such as the protection of providers' data collected on Global Positioning Systems (GPS) during shifts. Information security standards such as ISU 27001 provide a framework for managing, monitoring, and improving information security risks.[26]

Ethical Considerations for Biometric Technology in Training Programs

Use of biometric data as surveillance in training programs raises potential ethical concerns, especially related to sensitive information collected about learners' emotional states, cognitive load, and stress levels. Simulation training programs must balance the use of biometric data for performance improvement with ethical obligations to protect learners' rights. Without safeguards, biometric data may compromise learners' autonomy, violate privacy, or create a perceived culture of surveillance.[27] Some states in the United States safeguard biometric data and require both notice and informed written consent when nongovernmental organizations collect biometric information.[28] Data governance frameworks must address consent, data ownership, secure storage, and transparent access policies. Importantly, institutions should implement data minimization principles, collecting only what is necessary and ensuring proportional use in educational decision-making.[29]

Biometric sensors, including those relying on PPG, have known limitations in accuracy across diverse skin tones and physiologies.[30] Training programs seek transparency concerning facial recognition algorithms, especially given the high incidence of false positives among different demographic groups and risk of bias.[31] To ensure responsible implementation, simulation used in training programs must embed continuous ethical review, develop clear policies, and involve learners in discussions about how biometric data will be interpreted and applied.

Intersections of Biometric Technology With Educational Theory and Assessment Frameworks

Positioning biometric technology within educational theories and assessment frameworks will increase adoption in simulation and training programs. Rather than viewing biometric data solely for performance improvement, biometric data can improve training environments and curriculum if simulationists conceptualize data as part of a broader framework for formative assessment, self-regulated learning, and competency-based education. Biometric data contributes to formative assessment by offering real-time or postevent indicators of learner engagement, stress, or attention that inform targeted feedback and reflection.[32] Using biometric data for formative assessment supports learning and aligns with competency-based education. Biometric data collected in simulation may provide evidence simulation learners demonstrate competency in terms of psychophysiologic readiness and the "show how" level of the Miller Pyramid; in a patient care setting, biometric data may provide evidence of sustained performance under pressure and the "do" level of the Miller Pyramid.[33]

Concerns Related to Access, Data Integrity, and Interpretations

For biometric technology to advance in health care, end users will need more analysis capacity and transparency in software. The use of nondisclosed algorithms complicates analysis, impedes comparability between datasets, and obstructs standardization efforts.[34] Health care scientists and informaticists are particularly focused on the reliability and validity of biometric data across different sources; if data from various sources can be triangulated, health care systems can then select a single, effective biometric technology. Selecting the best fit biometric technology would enable smaller hospitals and rural areas to create smart environments. There is a critical need for software platforms to provide transparent raw data outputs. Moreover, methodological studies that compare algorithms used for analyzing biometric data are important for building trust in their reliability and validity.

Cost and access are the remaining barriers that must be overcome to expand the use of biometric technology in health care. Reducing the costs of hardware and software is essential to make biometric technologies more accessible to new users and to improve patient outcomes. Currently, there is a gap in the literature regarding continuous, long-term outpatient monitoring. Such monitoring could supplement office visits by providing insight into patients' functional ability in their everyday environments,[6] yet costs remain a significant barrier.

As economies of scale begin to lower prices, there is an opportunity for industry and regulatory partners to increase the availability of biometric technology. This expansion could extend not only to controlled simulation laboratories and real patient care settings but also to empirical research. In addition, expanding access to Wi-Fi will help take biometric technology to points of needs across inpatient and outpatient settings.

Recommendations for Practical Applications

As we look toward the future of biometric technology in health care, our goals center around practical applications that enhance clinician capabilities, rather than replacing them. Table 1 provides an overview of how health care simulation can support the development, implementation, and effectiveness of biometric technologies. These simulations are important for testing new applications such as deep learning algorithms to classify biometric data effectively and for iterative training sessions that refine technology to meet stringent accuracy thresholds. Research highlights the advantages of biometric technologies. For example, integrating wireless wearables into daily clinical operations enables ongoing health monitoring that is less invasive and more adaptable than conventional methods. A biometric approach not only deepens our understanding of patient health trends but also allows providers to make quicker, more informed decisions with real-time data.[35]

CONCLUSIONS

The simulation laboratory provides an ideal environment for testing biometric technology, including wearables, ambient intelligence, and telehealth. Simulation allows for standardized environments to facilitate the integration of biometric technology within the existing infrastructure of health care systems and across various clinicians, settings, and patient populations. Testing biometric technology in simulation represents a logical precursor to broader implementation in health care environments and community settings.

There is a significant need for collaboration among experts in simulation, informatics, patient safety, research, and health care quality. While biometric data points are commonly shared across simulation and patient care contexts, different communities will use data in distinct ways. Clinicians and regulators focus on preventing patient safety events, while researchers are interested in analyzing the context and causes of these events. Administrators aim to address safety and privacy challenges to reduce cost and expand access to biometric technology. Simulationists are uniquely positioned to bring together interprofessional teams that can test biometric technology for systems integration. This testing can improve patient identification, enhance security, streamline processes, reduce errors, increase efficiency, and, most importantly, improve safety outcomes.

ACKNOWLEDGMENTS

The authors acknowledge the Society for Simulation in Healthcare Technology Committee for guidance with the structure of this manuscript.

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